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THE OIL HEATING ASSOCIATION OF CANADA CLEAN AIR PROGRAM PHASE V: EVALUATION OF BURNERS WITH HIGH AND LOW SPEED MOTORS IN A DOMESTIC HOT WATER HEATER

by

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THE OIL HEATING ASSOCIATION OF CANADA CLEAN-AIR PROGRAM

PHASE V: EVALUATION OF BURNERS WITH HIGH AND LOW SPEED MOTORS IN A DOMESTIC HOT WATER HEATER*

by

T. D. Brown**

ABSTRACT

Operation of six test burners in the refractory lined combustion chamber of a domestic hot water heater showed that a burner capable of achieving a smoke number below one at all firing rates would do so at an excess-air level below sixty per cent ($CO_2 > 9\%$). Only the three burners which were equipped with retention heads could meet this smoke number requirement. The relative changes in mass flow due to changes in the chimney draft were greatest with these same retention head burners although the absolute magnitude of the changes was essentially constant for all burners when operated at the same firing rate.

The recovery rate of the furnace was largely independent of the burner used but was strongly dependent on firing rate and moderately dependent on the minimum excess-air level that the burner could achieve without smoke production.

The incorporation of a slip clutch produced significant reductions in both start-up and shut-down emissions of smoke and carbon monoxide. The minimum smoke emissions were associated with burners with high speed motors.

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*Prepared for the Equipment and Service Committee of the Oil Heating Association of Canada, Chairman, C. S. James.

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LE PROGRAMME DE PURIFICATION DE L'AIR DE L'ASSOCIATION DU CHAUFFAGE A L'HUILE DU CANADA PHASE V: L'EVALUATION DES BRULEURS A MOTEURS A HAUTE ET BASSE VITESSE DANS UN SYSTEME DE CHAUFFAGE A L'EAU CHAUDE*

par

T. D. Brown**

RESUME

Dans cette étude, on a démontré, après avoir procédé à l'essai de six brûleurs dans un foyer à revêtement réfractaire d'un système de chauffage à l'eau chaude, qu'un brûleur pouvant obtenir un taux de fumée inférieur à 1, à n'importe quel taux de chauffage, maintiendrait ce taux à un niveau excédant d'air inférieur à 60% (CO_2 9%). Seuls les trois brûleurs munis de têtes de rétention ont pu satisfaire ce taux de fumée requis. Les changements relatifs du flux causés par les variations du tirage de la cheminée étaient plus grands parmi ces mêmes brûleurs à têtes de rétention quoique la grandeur absolue des changements était essentiellement constante pour tous les brûleurs lorsqu'opérés au même taux de chauffage.

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*Préparé pour le Comité du service et de l'équipement de l'Association du chauffage à l'huile du Canada, Président, C.S. James.

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Le taux de récupération de la fournaise ne dépendait nullement du brûleur utilisé mais dépendait grandement du taux de chauffage et modérément du niveau minimum d'excédent d'air que le brûleur pouvait acquérir sans produire de la fumée.

L'addition d'un accouplement à débrayage produisit des réductions significatives au démarrage et à l'arrêt d'émission de fumée et de monoxyde de carbone. Les émissions minimales de fumée étaient associées aux brûleurs à moteurs à haute vitesse.

CONTENTS

Page

Abstract i

Resumé ii

Contents iv

Introduction 1

The Hot Water Heater 1

Steady Running Combustion Performance 2

Combustion Performance at the Standard Draft Condition 2
Combustion Performance Under Modified Draft Conditions..... 3
Smoke Production Under Modified Draft Conditions 4
Carbon Monoxide Production Under Modified Draft Conditions 4
Nitric Oxide Emissions 5
Flue Gas Losses and Recovery Rate 5

Start-Up and Shut-Down Combustion Performance 7

Smoke Index 7
Peak Carbon Monoxide Concentrations 8

Conclusions 9

References 10

Appendix A: Tabulation of Test Data 11

Steady Running Performance:

Table A1: Combustion Conditions: Beckett 3450-Aero 3450 rpm.. 11
Table A2: Combustion Conditions: Aero 1725-Anthes 1725 rpm... 12
Table A3: Combustion Conditions: Terry 1725-Beckett 1725 rpm. 13
Table A4: The Relative Effect of Furnace Collar Draft On Burner Mass Flow..... 14
Table A5: The Absolute Effect of Furnace Collar Draft on Burner Mass Flow 15
Table A6: Nitric Oxide Emissions 16
Table A7: Nitric Oxide Emissions 17
Table A8: Nitric Oxide Emissions 18

Page

Table A9: Flue Gas Losses 19
Table A10: Flue Gas Losses 20
Table A11: Flue Gas Losses 21
Table A12: Recovery Rates 22

Start-Up and Shut-Down Performance:

Table A13: Smoke Index 23
Table A14: Smoke Index 24
Table A15: Smoke Index 25
Table A16: Peak Carbon Monoxide Concentrations 26
Table A17: Peak Carbon Monoxide Concentrations 27
Table A18: Peak Carbon Monoxide Concentrations 28

INTRODUCTION

The background to the Oil Heating Association of Canada Clean-Air Program at the Canadian Combustion Research Laboratory (CCRL) has been described in Mines Branch Investigation Report IR 73-32[1], entitled "Phase I: Facilities, Techniques and Procedures". Phase II, III and IV of this program, which dealt with test data obtained during the evaluation of six yellos-flame domestic burners in two warm air furnaces and a hot water boiler were published as Mines Investigation Reports IR 73-33[2], IR 73-70[3] and IR 74-52[4] respectively. This report covers Phase V and is devoted to the performance evaluation of the same six test burners in a domestic hot water heater.

THE HOT WATER HEATER

The domestic hot water heater used in these tests was manufactured by Aero Tool Company and was equipped with a ceramic fibre combustion chamber.

Prior to starting a combustion test the unit was charged with cold city water and the burner was adjusted to give a minimum smoke condition with the barometric damper set at the "standard" draft condition of -0.02 in. WC. The unit was subsequently shut-down, drained and re-charged with cold city water, the recovery cycle was then initiated. The duration of the test was determined solely by the heat transferred to the charge and the test was ended automatically by the high temperature control of the system. A series of evaluations at different furnace draft conditions were also made using this same procedure.

The unit was operated throughout a complete recovery cycle during which time all the steady-state combustion performance parameters were measured; replicate start-up and shut-down measurements were made separately on a re-charged heater.

The discussion of the test data is presented in the same order as the data tabulation in Appendix A.

STEADY RUNNING COMBUSTION PERFORMANCE

The test procedure required that the burners were adjusted to give a zero to one smoke number at a "standard" draft of -0.02 in. WC. defined in IR 73-32[1].

Combustion Performance at the Standard Draft Condition

The seven burner/firing rate combinations that were incapable of achieving CO_2 levels above 9% with smoke numbers below one at the standard draft are shown below in Table 1. The remaining eleven burner/firing rate combinations were all capable of meeting this combined standard.

TABLE 1

Burners Not Achieving Smoke Number Below 1

Burner	Firing Rate	Minimum Smoke Number	CO_2%
Anthes	0.5	2	7.6
Terry	0.5	1-2	7.8
	0.75	1-2	8.8
	1.00	2-3	9.6
Beckett S	0.5	4-5	9.8
(1725 rpm)	0.75	2-3	8.3
	1.00	1-2	8.8

It appears that the performance of the burners in the hot water heater is different to that measured in the test furnace during Phases II,III and IV. In these previous evaluations poor performance at the lowest firing rate was a characteristic of all six burners and, at higher firing rates several burners only achieved the smoke number criterion at the expense of a high excess-air level. In the hot water heater, poor performance at the

lowest firing rate was a characteristic of the two standard head and the single swirl head burners; at other firing rates, if a burner met the smoke number criterion it also met the excess-air level criterion.

Carbon monoxide production at the standard draft condition was above 25 ppm for the several burner/firing rate combinations listed below:

TABLE 2

Carbon Monoxide Production

Carbon Monoxide Concentration	Burner	Firing Rate US gph
> 25 ppm	Beckett 3450	1.00
..	Aero 3450	0.5
..	Aero 1725	0.5 0.75 1.00
..	Anthes 1725	0.5
..	Terry 1725	0.5 1.00
..	Beckett 1725	0.5 0.75

Combustion Performance Under Modified Draft Conditions

The modified draft conditions were obtained by altering the setting of the barometric damper without changing any of the burner controls. The results therefore reflect differences in performance that could be expected due to variations in external wind conditions.

The change to a higher draft level (-0.05 in. W.C.) led invariably to an increase in excess-air level and a smoke number less than unity, whereas reduced draft level (+0.05 in. W.C.) always caused a decrease in excess-air level but this resulted in significant changes in the smoke number for one burner only.

The changes in excess-air level due to the impressed change in the chimney draft have been calculated as relative change in air flow through the burner per 0.01 in. W.C. change in chimney draft in Table A4.

Where identical blast tube configurations were used with different speed motors (Aero 3450 rpm and 1725 rpm)the performance with the low speed motor was more susceptible to changes in chimney draft. This is in agreement with the results obtained on the hot water boiler.

Table A4 indicates that, in general, the burners equipped with retention heads are most susceptible to variations in chimney draft. However, this result must be considered with care since these burners did not operate at the same mass flow under the "standard" condition. Table A5 lists the absolute mass flow rate changes due to the impressed draft changes in lbs of air per lb of fuel and it can be seen that although the absolute change decreased as the firing rate increased there was no significant difference in this respect between the retention head and non-retention head burners.

Smoke Production Under Modified Draft Conditions

The only burner which showed a significant change in smoke number at the reduced draft condition was the Aero 1725 rpm at the 0.5 and 0.75 firing rates. At both firing rates the smoke number changed by one unit per 0.01 in. W.C. change in the collar draft.

Carbon Monoxide Production Under Modified Draft Conditions

In no instances did the changes in draft condition lead to carbon monoxide concentrations greater than 100 ppm. The concentrations at all test conditions were higher than those observed in burners tested in other furnaces.

Nitric Oxide Emissions

A plot of the nitric oxide emissions at the "standard" draft condition is shown in Figure 1. The line shown is the "best fit" quadratic to the data points and does not show any general change in nitric oxide emission with firing rate. The results for individual burners showed that the two Aero burners (3450 rpm and 1725 rpm) produced the highest NO emissions.

Flue Gas Losses and Recovery Rate

The measured flue gas losses are shown in Tables A9-A11 together with flue gas losses corrected to temperatures of 300°F and 400°F.

The exhaust gas temperature which was above 500°F at the"standard" draft and a firing rate of 0.5 US gph, increased gradually to 700°F maximum as the firing rate increased to a maximum of 1.0 US gph. For two burners this increase in flue gas temperature, which would normally increase the flue gas loss, was over-compensated by a reduced excess-air level and the net result was a reduction in flue gas loss. The remaining four burners all showed a consistent increase in flue gas loss with increased firing rate. The increase flue gas loss is reflected in the recovery rates (measured indirectly by CSA Standard 140.12) that are listed in Table A12. The recovery rate is defined as the quantity of water in gallons per hour that the equipment will heat through 100°F.

Firing rate has a dominant effect on recovery rate with excess-air level being of secondary importance. The relationship between recovery rates, firing rate, and CO_2 level in these experiments can be described by the linear equations.

$$\text{Recovery Rate (Imperial gallons/hour)} = a + b \cdot \left[CO_2\right]$$

where a and b are both dependent on firing rate , F , in US gph

$$a = 8.8 + 66F$$

$$b = 0.025 + 2.7F$$

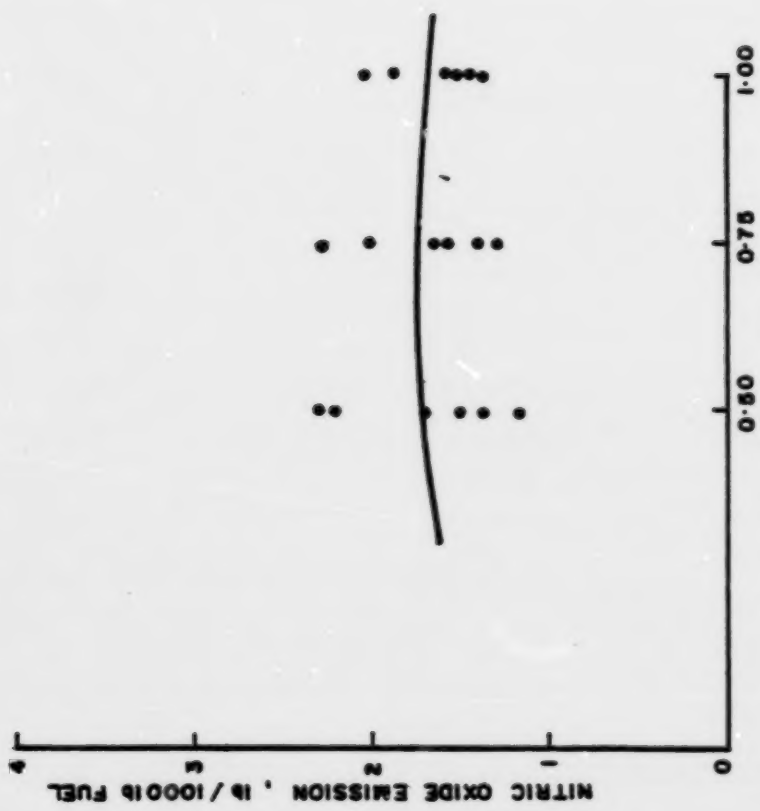

Figure 1. Nitric oxide emission as a function of firing rate.

The recovery rate is apparently independent of the burner except insofar as the burner limits the maximum value of (CO_2) that can be achieved without significant smoke production. Changes in the collar draft affect the recovery rate within the framework of the above equations as a consequence of their effect on (CO_2).

START-UP AND SHUT-DOWN COMBUSTION PERFORMANCE

Smoke Index

It can be seen from Tables A13-A15, that in tests without a slip clutch, the start-up gave a higher smoke index (SI) than shut-down in 32 out of 54 cases. By comparison, in tests with a slip clutch the start-up gave a higher smoke index than shut-down in 50 out of 54 cases; in three of the four remaining tests the start-up and shut-down smoke index were both zero. In addition, the incorporation of a slip clutch improved performance significantly by reducing the smoke index in 28 out of 54 start-up tests and in 52 out of 54 shut-down tests.

It should be remembered that the soot generated on shut-down comes from the flame alone whereas the soot generated on start-up is a composite quantity of soot from the flame and soot detached by the explosive ignition from the heat transfer surfaces. Improvements in shut-down performance will therefore lead to improvements in start-up performance whereas the reverse is not necessarily true.

When a slip clutch was incorporated in these tests the burners equipped with high speed motors showed overall reductions in smoke index at all firing rates and reductions in smoke index on start-up at the two highest firing rates; at the lowest firing rate the smoke index on start-up showed a small increase ($\Delta SI = 0.1$). The burners equipped with low-speed motors showed overall reductions in smoke index on shut-down at all firing rates but an overall reduction in smoke index on start-up was only observed at the highest firing rate.

The lowest overall smoke indices (i.e. all firing rates, start-up and shut-down) measured after incorporation of a slip clutch were observed with the high speed motor burners, a result which is in agreement with those reported in Phase IV of the project.

Peak Carbon Monoxide Concentration

The peak carbon monoxide levels (Tables A16-A18) were usually below 0.1%; the exceptions are shown in Table 3 below:

TABLE 3

Burners Showing High Transient Carbon Monoxide Concentrations

WITH SLIP CLUTCH	Aero Burner	0.75 US gph	Start-Up	at +0.05 " WC	CO = 0.21%
	Anthes Burner	1.00 US gph	Shut-down	at -02" WC	CO = 0.12%
				at +05" WC	CO = 0.25%
WITHOUT SLIP CLUTCH	Aero Burner 3450 rpm	0.75 US gph	Shut-down	at +05" WC	CO = 0.34%
		1.00 US gph	Shut-down	at -02" WC	CO = 0.40%
				at +05" WC	CO = 0.74%
	Aero Burner 1725 rpm	0.75 US gph	Shut-down	at +05" WC	CO = 0.12%

The incorporation of a slip clutch led to the following changes in start-up and shut-down performance.

Improved start-up performance:	19 out of 54 tests
Impaired start-up performance:	20 out of 54 tests
No change:	15 out of 54 tests
Improved shut-down performance:	39 out of 54 tests
Impaired shut-down performance:	1 out of 54 tests
No change:	14 out of 54 tests

The incorporation of a slip clutch often led to the peak CO concentration being reduced to levels below 100 ppm (Tables A16-A17). In other cases the margin of improvement or deterioration was small (Table A18).

CONCLUSIONS

Seven out of eighteen burner/firing rate combinations could not meet the combined "standard" of $CO_2 > 9\%$ and smoke number < 1. The retention head burners met the combined standard at all firing rates. No significant differences in the changes in absolute mass flow through the burners due to impressed changes in collar draft were observed; the relative changes were however greatest with the retention head burners. The changes in smoke number and carbon monoxide production associated with the changes in collar draft were generally small.

The recovery rate of the hot water heater was independent of the burner used, showed a strong primary dependence on firing rate and showed a secondary dependence on CO_2 level. The recovery rate for all burners was represented by the general equation:

$$\text{Recovery Rate (Imperial gallons/hr)} = a + b\left[CO_2\right]$$

where a and b are both dependent on firing rate F in US gph

$$a = 8.8 + 66F$$

$$b = 0.025 + 2.7F$$

The incorporation of a slip clutch reduced the smoke index in the majority (74%) of cases; and improved or left unaltered the peak carbon monoxide concentration in 84% of the tests.

REFERENCES

1. The Oil Heating Association of Canada Clean Air Program: Phase I: Facilities Techniques and Procedures, Mines Branch Investigation Report IR 73-32, Department of Energy, Mines and Resources, Ottawa, Canada.

2. The Oil Heating Association of Canada Clean Air Program: Phase II: Evaluation of Burners With High Speed Motors in Warm Air Furnaces, Mines Branch Investigation Report IR 73-33. Department of Energy, Mines and Resources, Ottawa, Canada.

3. The Oil Heating Association of Canada Clean Air Program: Phase III: Evaluation of Burners with Low Speed Motors in Warm Air Furnaces, Mines Branch Investigation Report IR 73-70, Department of Energy, Mines and Resources, Ottawa, Canada.

4. The Oil Heating Association of Canada Clean Air Program: Phase IV: Evaluation of Burners With High and Low Speed Motors In a Domestic Hot Water Boiler, Mines Branch Investigation Report IR 74-43, Department of Energy, Mines and Resources, Ottawa, Canada.

APPENDIX A: TABULATION OF TEST DATA

TABLE A1

STEADY RUNNING PERFORMANCE

Combustion Conditions

Burner	Nozzle US gph	Draft Inch wc	CO_2 %	O_2 %	CO %	Smoke Number
Beckett 3450 rpm	0.5	-0.02	10.75	6.2	0.00	1
		-0.05	9.45	8.0	.005	1
		+0.05	11.9	4.3	0.00	4
	0.75	-0.02	12.25	4.15	0.00	1
		-0.05	10.95	5.35	.005	1
		+0.05	12.85	3.0	.005	1
	1.00	-0.02	13.0	3.0	.005	0
		-0.05	11.825	4.2	trace	0
		+0.05	13.75	2.45	.005	0
Aero 3450 rpm	0.5	-0.02	9.75	6.85	0.005	0
		-0.055	8.6	7.8	0.005	0
		+0.05/.055	11.25	4.05	trace	0
	0.75	-0.02	12.25	4.05	0.0	0-1
		-0.05	11.35	5.2	0.0	0
		+0.05	13.9	1.95	trace	3
	1.00	-0.02	13.45	2.7	0.0	0
		-0.05	12.75	3.8	0.0	0
		+0.05	14.45	1.55	0.0	3

Thermostat Setting 150°F

TABLE A2

STEADY RUNNING PERFORMANCE

Combustion Conditions

Burner	Nozzle US gph	Draft Inch wc	CO_2 %	O_2 %	CO %	Smoke Number
Aero		-0.02	10.3	6.4	0.005	1
1725 rpm	0.5	-0.05	9.4	8.05	0.0	0
		+0.05	14.1	1.225	.005	1
		-0.02	11.9	3.75	0.005	1
	0.75	-0.05	10.8	5.35	trace	1
		+0.05/0.045	14.15	1.075	.01	1
		-0.02	12.55	2.95	.005	1
	1.00	-0.05	11.7	4.0	.005	0
		+0.05	13.65	1.8	.005	3
Anthes		-0.02	7.55	10.45	.005	2
1725 rpm	0.5	-0.05	6.95	11.2	.0075	2
		+0.05	8.75	8.85	0.00	2
		-0.02	10.0	7.0	0.00	0
	0.75	-0.05	9.9	7.7	0.00	0
		+0.05	11.6	5.45	0.005	0
		-0.02	11.3	5.15	0.00	1
	1.00	-0.05	10.8	5.7	.005	1
		+0.05	12.2	4.3	.005	3

Thermostat Setting 150°F

TABLE A3

STEADY RUNNING PERFORMANCE

Combustion Conditions

Burner	Nozzle US gph	Draft Inch wc	CO_2 %	O_2 %	CO %	Smoke Number
Terry 1725 rpm	0.5	-0.02	7.75	10.15	.005	1
		-0.05	7.15	11.1	0.00	0
		+0.05	8.75	8.95	.005	2
	0.75	-0.02	8.8	8.85	trace	1-2
		-0.05	8.55	9.7	.005	1-2
		+0.05	9.7	8.6	0.00	1-2
	1.00	-0.02	9.6	7.5	.005	3
		-0.05	9.05	8.1	.005	2
		+0.05	10.6	7.0	.005	3
Beckett 1725 rpm	0.5	-0.02	8.5	9.8	.005	5
		-0.05	8.0	10.95	.005	4
		+0.05	10.05	6.85	.005	6
	0.75	-0.02	8.25	9.05	.005	3
		-0.05	7.9	9.3	.005	2
		+0.05	8.85	8.15	.005	4
	1.00	-0.02	8.8	8.3	trace	2
		-0.05	8.4	8.8	trace	1
		+0.05	9.15	7.75	trace	3

Thermostat Setting 150°F

TABLE A4

STEADY RUNNING PERFORMANCE

The Relative Effect of Furnace Collar Draft On Burner Mass Flow

Burner	Firing Rate US gph	Change in Air Flow: % per 0.01 In. WC	
		Standard to -0.05"WC	Standard to +0.05"WC
Beckett 3450 rpm	0.5	4.79	1.46
	0.75	4.34	0.76
	1.00	3.79	0.90
Aero 3450 rpm	0.5	3.84	1.85
	0.75	2.96	1.94
	1.00	2.19	1.22
Aero 1725 rpm	0.5	3.27	4.2
	0.75	3.61	2.61
	1.00	2.63	1.4
Anthes 1725 rpm	0.5	2.86	1.99
	0.75	0.31	2.04
	1.00	1.62	1.16
Terry 1725 rpm	0.5	2.81	1.68
	0.75	1.12	1.31
	1.00	2.13	1.37
Beckett 1725 rpm	0.5	2.15	2.25
	0.75	1.57	0.95
	1.00	1.67	0.54

TABLE A5

STEADY RUNNING PERFORMANCE

The Absolute Effect of Furnace Collar Draft on Burner Mass Flow

Burner	Firing Rate US gph	Change in Air Flow lbs/lb Fuel/.01" W.C.	
		Increased Draft	Reduced Draft
Beckett 3450 rpm	0.5	0.9	0.3
	0.75	0.7	0.1
	1.00	0.6	0.1
Aero 3450 rpm	0.5	0.8	0.4
	0.75	0.5	0.3
	1.00	0.3	0.2
Aero 1725 rpm	0.5	0.7	0.9
	0.75	0.6	0.5
	1.00	0.4	0.2
Anthes 1725 rpm	0.5	0.8	0.6
	0.75	0.07	0.4
	1.00	0.3	0.2
Terry 1725 rpm	0.5	0.8	0.5
	0.75	0.3	0.3
	1.00	0.5	0.3
Beckett 1725 rpm	0.5	0.5	0.6
	0.75	0.4	0.2
	1.00	0.4	0.1

TABLE A6

STEADY RUNNING PERFORMANCE

Nitric Oxide Emissions

Burner	Nozzle US gph	Nominal Draft Inch wc	Nitric Oxide Emissions	
			ppm	lb/1000 lb Fuel
Beckett 3450 rpm	0.5	+0.05	88	1.50
		-0.02	88.5	1.68
		-0.07	78.5	1.70
	0.75	+0.05	101.5	1.58
		-0.02	99.5	1.64
		-0.07	91.5	1.70
	1.00	+0.05	112	1.61
		-0.02	101.5	1.56
		-0.07	92.5	1.59
Aero 3450 rpm	0.5	+0.05	99	1.79
		-0.02	106	2.22
		-0.07	86	2.05
	0.75	+0.05	131	1.86
		-0.02	121.5	2.00
		-0.07	110	1.97
	1.00	+0.05	126.5	1.71
		-0.02	127.5	1.88
		-0.07	121	1.90

TABLE A7

STEADY RUNNING PERFORMANCE

Nitric Oxide Emissions

Burner	Nozzle US gph	Nominal Draft Inch wc	Nitric Oxide Emissions	
			ppm	1b/1000 1b Fuel
Aero		+0.05	130	1.81
1725 rpm	0.5	-0.02	115.3	2.28
		-0.07	100.5	2.19
		+0.05	139	1.93
	0.75	-0.02	135	2.29
		-0.07	123.5	2.33
	1.00	+0.05	114.5	1.66
		-0.02	128	2.05
		-0.07	116.5	2.02
Anthes		+0.05	52	1.23
1725 rpm	0.5	-0.02	42	1.16
		-0.07	35.5	1.07
		+0.05	92	1.61
	0.75	-0.02	78.5	1.61
		-0.07	71	1.47
		+0.05	102.5	1.70
	1.00	-0.02	80.5	1.45
		-0.07	76.5	1.45

TABLE A8

STEADY RUNNING PERFORMANCE

Nitric Oxide Emissions

Burner	Nozzle US gph	Nominal Draft Inch wc	Nitric Oxide Emissions	
			ppm	lb/1000 lb Fuel
Terry 1725 rpm	0.5	+0.05	59	1.39
		-0.02	48.75	1.30
		-0.07	48.5	1.41
	0.75	+0.05	61.5	1.30
		-0.02	55	1.29
		-0.07	60.75	1.47
	1.00	+0.05	69.5	1.34
		-0.02	65.75	1.41
		-0.07	62.	1.41
Beckett 1725 rpm	0.5	+0.05	78.5	1.61
		-0.02	60	1.46
		-0.07	51	1.32
	0.75	+0.05	47	1.10
		-0.02	55	1.38
		-0.07	48	1.26
	1.00	+0.05	58	1.311
		-0.02	64.5	1.514
		-0.07	57.5	1.418

TABLE A9

STEADY RUNNING PERFORMANCE

Flue Gas Losses

Burner	Firing Rate US gph	Nominal Draft Inch wc	CO_2	Flue Gas Temperature °F	Flue Gas Losses %
Beckett 3450 rpm	0.5	+0.05	11.9	456.5	15.46
		-0.02	10.75	539.5	18.62
		-0.07	9.45	539	20.19
	0.75	+0.05	12.85	572	17.49
		-0.02	12.25	665.5	20.25
		-0.07	10.95	676.5	22.07
	1.00	+0.05	13.75	669.5	18.94
		-0.02	13.0	727.5	20.93
		-0.07	11.825	742	22.62
Aero 3450 rpm	0.5	+0.05	11.25	476	16.46
		-0.02	9.7	550.25	20.18
		-0.07	8.6	581	22.88
	0.75	+0.05	13.9	501.5	15.20
		-0.02	12.25	633	19.47
		-0.07	11.35	649.5	20.86
	1.00	+0.05	14.45	626.5	17.49
		-0.02	13.45	693.5	19.73
		-0.07	12.75	716	20.93

TABLE A10

STEADY RUNNING PERFORMANCE

Flue Gas Losses

Burner	Firing Rate US gph	Nominal Draft Inch wc	CO_2	Flue Gas Temperature °F	Flue Gas Losses %
Aero		+0.05	14.1	425.5	13.47
1725 rpm	0.5	-0.02	10.3	526.5	18.76
		-0.07	9.4	543.5	20.39
		+0.05	14.15	543.5	15.95
	0.75	-0.02	11.9	670.5	20.75
		-0.07	10.8	683.5	22.46
		+0.05	13.65	644.5	18.48
	1.00	-0.02	12.55	707.5	20.94
		-0.07	11.7	724.5	22.34
Anthes		+0.05	8.75	529.5	20.92
1725 rpm	0.05	-0.02	7.55	598	25.69
		-0.07	6.95	603.5	27.50
		+0.05	11.6	676.5	21.25
	0.75	-0.02	10.0	725.5	24.88
		-0.07	9.9	733.5	25.28
		+0.05	12.2	747	22.28
	1.00	-0.02	11.3	783.5	24.39
		-0.07	10.8	806	25.77

TABLE A11

STEADY RUNNING PERFORMANCE

Flue Gas Losses

Burner	Firing Rate US gph	Nominal Draft Inch wc	CO_2	Flue Gas Temperature °F	Flue Gas Losses %
Terry 1725 rpm	0.5	+0.05	8.75	579	22.54
		-0.02	7.75	549.5	23.43
		-0.07	7.15	572	25.69
	0.75	+0.05	9.7	657.5	23.38
		-0.02	8.8	691.5	26.12
		-0.07	8.55	716	27.49
	1.00	+0.05	10.6	712	23.53
		-0.02	9.6	747	26.24
		-0.07	9.05	771.5	28.15
Beckett 1725 rpm	0.05	+0.05	10.05	476	17.59
		-0.02	8.5	555.5	22.20
		-0.07	8.0	571	23.69
	0.75	+0.05	8.85	665.5	25.18
		-0.02	8.25	702	27.73
		-0.07	7.9	705	28.73
	1.00	+0.05	9.15	765	27.73
		-0.02	8.8	778	28.95
		-0.07	8.4	794.5	30.52

TABLE A12

STEADY RUNNING PERFORMANCE

Recovery Rate
(Measured at the Standard Draft Condition)

Burner	Firing Rate US gph	Recovery Imp gph
Beckett 3450 rpm	0.5	56.2
	0.75	82.7
	1.00	109.4
Aero 3450 rpm	0.5	55.2
	0.75	83.5
	1.00	111.0
Aero 1725 rpm	0.5	56.2
	0.75	80.4
	1.00	109.4
Anthes 1725 rpm	0.5	51.5
	0.75	78.0
	1.00	104.7
Terry 1725 rpm	0.5	53.0
	0.75	76.7
	1.00	102.2
Beckett 1725 rpm	0.5	53.8
	0.75	75.2
	1.00	98.6

TABLE A13

START-UP AND SHUT-DOWN PERFORMANCE

Smoke Index

Burner	Firing Rate US gph	Nominal Draft Inch wc	Smoke Index			
			Without Slip Clutch		With Slip Clutch	
			Start Up	Shut Down	Start Up	Shut Down
Beckett 3450 rpm	0.5	-0.02	1.7	2.6	0.9	0.5
		-0.05	1.0	1.2	1.5	0.6
		+0.05	4.1	3.5	9.4	2.2
	0.75	-0.02	4.5	2.2	5.9	0.8
		-0.05	2.6	1.2	2.3	0.4
		+0.05	5.6	3.1	8.2	1.0
	1.00	-0.02	1.5	2.2	2.6	0.7
		-0.05	0.9	1.2	1.8	0.4
		+0.05	4.2	4.1	4.0	1.5
Aero 3450 rpm	0.5	-0.02	1.7	6.4	0	0
		-0.05	1.6	3.0	0.3	0
		+0.05	1.9	0.2	0.6	0.2
	0.75	-0.02	2.1	4.9	0.5	0.4
		-0.05	1.9	4.4	0.4	0.3
		+0.05	4.8	7.6	0.4	0.6
	1.00	-0.02	1.9	5.5	1.2	0
		-0.05	2.6	5.3	0.4	0
		+0.05	3.6	7.8	4.1	0.8

TABLE A14

START-UP AND SHUT-DOWN PERFORMANCE

Smoke Index

Burner	Firing Rate US gph	Nominal Draft Inch wc	Smoke Index			
			Without Slip Clutch		With Slip Clutch	
			Start Up	Shut Down	Start Up	Shut Down
Aero 1725 rpm	0.5	-0.02	1.6	1.4	0	0
		-0.05	1.4	1.2	8	1
		+0.05	6.3	2.7	16	5.6
	0.75	-0.02	4.0	3.3	0	0
		-0.05	1.6	1.5	2.2	5
		+0.05	13.8	8.4	25.3	8.2
	1.00	-0.02	1.2	3.7	1.1	0.1
		-0.05	1.4	1.7	1.0	0
		+0.05	6.2	7.7	9.3	4.0
Anthes 1725 rpm	0.5	-0.02	4.1	2.5	4.4	1.1
		-0.05	5.6	1.75	5.1	1.2
		+0.05	5.9	4.0	5.2	1.8
	0.75	-0.02	2.5	3.7	2.1	1.2
		-0.05	1.9	2.6	1.9	0.9
		+0.05	3.5	5.1	3.6	2.4
	1.00	-0.02	3.8	4.4	3.7	0.5
		-0.05	3.5	3.8	3.4	0.5
		+0.05	5.3	5.0	6.0	1.3

TABLE A15

START-UP AND SHUT-DOWN PERFORMANCE

Smoke Index

Burner	Firing Rate US gph	Nominal Draft Inch wc	Smoke Index			
			Without Slip Clutch		With Slip Clutch	
			Start Up	Shut Down	Start Up	Shut Down
Terry		-0.02	2.4	3.2	2.7	0.2
1725 rpm	0.5	-0.05	2.1	1.6	2.3	0
		+0.05	4.7	4.3	6.5	1.6
		-0.02	3.2	2.1	6.3	1.0
	0.75	-0.05	4.9	1.7	5.2	.6
		+0.05	3.6	3.5	3.8	1.7
		-0.02	5.5	3.3	7.5	1.0
	1.00	-0.05	5.3	2.0	4.1	0.2
		+0.05	11.4	4.5	8.6	3.2
Beckett		-0.02	5.4	2.0	5.2	0.2
1725 rpm	0.5	-0.05	4.1	1.1	4.7	0.7
		+0.05	13.1	3.4	16.5	3.0
		-0.02	5.9	2.3	5.7	0.7
	0.75	-0.05	5.7	2.0	4.0	0.2
		+0.05	9.3	3.4	9.3	0.9
		-0.02	4.4	2.8	4.2	0.4
	1.00	-0.05	.9	2.3	2.8	0.3
		+0.05	6.7	4.4	6.8	0.9

TABLE A16

START-UP AND SHUT-DOWN PERFORMANCE

Peak Carbon Monoxide Concentrations

Burner	Firing Rate US gph	Nominal Draft Inch wc	Peak Carbon Monoxide - %			
			Without Slip Clutch		With Slip Clutch	
			Start Up	Shut Down	Start Up	Shut Down
Beckett 3450 rpm	0.5	+0.05	0	0.005	0	0.005
		-0.02	trace	trace	0	0
		-0.07	trace	0	trace	0
	0.75	+0.05	0	0.035	0	0.035
		-0.02	0	0	trace	0
		-0.07	trace	0	trace	0
	1.00	+0.05	0	0.038	0	0.035
		-0.02	trace	0.0125	trace	0.01
		-0.07	trace	0	trace	0
Aero 3450 rpm	0.5	+0.05	trace	0.10	0	0
		-0.02	.005	0.015	0	0
		-0.07	trace	trace	0	0
	0.75	+0.05	trace	0.34	0	0
		-0.02	0.00	0.045	trace	0
		-0.07	0.00	0.025	trace	0
	1.00	+0.05	0	0.74	0	trace
		-0.02	0	0.395	0	0
		-0.07	0	0.17	0	0

TABLE A17

START-UP AND SHUT-DOWN PERFORMANCE

Peak Carbon Monoxide Concentrations

Burner	Firing Rate US gph	Nominal Draft Inch wc	Peak Carbon Monoxide - %			
			Without Slip Clutch		With Slip Clutch	
			Start Up	Shut Down	Start Up	Shut Down
Aero 1725 rpm	0.5	+0.05	0.012	trace	0	0
		-0.02	0.15	trace	0	0
		-0.07	.025	trace	.005	trace
	0.75	+0.05	0	0.123	0.205	0.02
		-0.02	trace	0.015	0.0035	0
		-0.07	trace	0	0	0
	1.00	+0.05	0	0.0725	0	0.0125
		-0.02	trace	0.020	0	0
		-0.07	trace	0	trace	0
Anthes 1725 rpm	0.5	+0.05	0.057	0.005	0.035	0
		-0.02	0.05	0.005	0.060	0
		-0.07	0.075	0	0.076	0
	0.75	+0.05	0.007	0.081	0	0
		-0.02	0.015	0.02	0	0
		-0.07	0.007	0	0	0
	1.00	+0.05	0.015	0.251	0.005	0
		-0.02	0.005	0.117	trace	0
		-0.07	0.007	0.053	trace	0

TABLE A18

START-UP AND SHUT-DOWN PERFORMANCE

Peak Carbon Monoxide Concentrations

Burner	Firing Rate US gph	Nominal Draft Inch wc	Peak Carbon Monoxide - %			
			Without Slip Clutch		With Slip Clutch	
			Start Up	Shut Down	Start Up	Shut Down
Terry 1725 rpm	0.5	+0.05	0.038	0.02	0.01	0.015
		-0.02	0.070	0.01	0.03	0.005
		-0.07	0.055	0	0.04	0.005
	0.75	+0.05	trace	0.007	0.005	0.010
		-0.02	0.015	0.010	0.02	0.005
		-0.07	0.016	0.010	0.022	trace
	1.00	+0.05	0.005	0.020	0.005	0.017
		-0.02	0.005	0.010	0.005	0.010
		-0.07	0.005	0.010	0.007	0
Beckett 1725 rpm	0.5	+0.05	0.01	0.025	0.015	0.025
		-0.02	0.03	0.0175	0.03	0.01
		-0.07	0.053	0.0175	0.05	0.015
	0.75	+0.05	0.04	0.02	0.02	0.015
		-0.02	0.0525	0.03	0.04	0.023
		-0.07	0.06	0.03	0.065	0.02
	1.00	+0.05	0.005	0.023	0.01	0.02
		-0.02	0.025	0.30	0.02	0.02
		-0.07	0.025	0.035	0.02	0.02